Signal Processing and Soft Computing Techniques for Single and Multiple Power Quality Events Classification

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***Abstract*—In this paper review of various methods and approaches that are used for the detection and classification of power quality (PQ) events are presented. Survey has been divided into two main categories one in which only single events are considered and another in which combined events are considered. Table has been also designed to present the comparative analysis of some references. Application of wavelet, need of power quality indices and optimization techniques has been also described in the paper. The aim of this paper is to show the Performance of various methodologies so that appropriate technique would be used for the detection and classification of PQ events.**

***Index Terms*—PQ, Signal Processing, Soft-computing.**

I. Introduction

The interest in developing new approaches and methodologies for analysis of power quality [9] [10] is increasing because the electrical power system have become disturbed due to slow and sudden variation in voltage and current. These variations occur due to the non linear devices, electronic devices and instead of this their use are also increasing rapidly. That's why the need of disturbance free electricity is growing. This is achieved by continuous monitoring [11], because for their mitigation, sources and causes of the disturbances must be known. PQ indices are the criterion which are based on the PQ standards [8] to notice the effect of disturbances such as transient, harmonics, flickers, voltage variation, etc. indices which are based on the Fourier derived techniques have some limitations because they provide accurate results only for the stationary signals. Hence for the analysis of non-stationary signals new PQ indices have been proposed based on short-time Fourier transform (STFT), Wavelet packet transform[14], kalman filter.

Now for the classification of electrical disturbances [4] some research and development of various methods have been done so that automatic identification of the problem can be achieve. As to detect the disturbance manually, then to find the occurrence time of event, and finally disturbance classification becomes very difficult and costly. For detection and classification of PQ events various signal processing tools have been described. Further intelligent techniques used for classification were also discussed along with some optimization techniques in [12], [31] and [37]. Different strategies for analysis of non stationary signals have been compared such as STFT, Gabor Transform (GT), S-transform (ST), Wavelet transform (WT), Kalman filters (KF) etc. They are compared on the basis of frequency and time resolution, convergence, signal to noise ratio. Similarly the algorithms used for classifying power disturbances were compared such as Artificial neural network (ANN),Support vector machine (SVM), Fuzzy logic (FL), Bayesian classifier (BC), Neural network (NN), multi-layer perceptron (MLP) and back propagation NN. They are compared on the basis of classification accuracy, flexibility and time consumed. Wavelet transform is an effective technique for feature extraction and when combined with artificial intelligent methods, this can be used for the classification purpose. WT have been used by researchers in various applications. The applications of wavelets in analysis of PQ have been described in [32].Another form of wavelet i.e. multiwavelet approach has been also referred by authors in [34]-[35] for the analysis detection and classification of PQ events. Power quality events and then disturbances (which occur after a fault event) are classified in [7]. Some more techniques other than traditional techniques are also used by the researchers such as Hilbert-Huang Transform [19] , 3-D space representation based [16], TT transform based [22], and PQ analyzers[6] for classification of PQ events.

In this paper an evaluation of the approaches and methodologies developed for PQ analysis in transmission and distribution system along with anomalies classification, is done. For this, the paper has been divided into four main sections. Second section includes review of the techniques that were used by the authors for classification of single disturbances only. Different references for single and combined events are discussed in the coming section and a comprehensive analysis of some important contribution to the field has also been elaborated.

Combined disturbances are again divided into two sub sections one which only includes harmonic along with other disturbances and another in which some other combination of disturbances are presented. 4 section presents comparative analysis. Finally in section 5, conclusions and future scope are discussed.

II. Single Pq Events

Some researchers perform analysis of single PQ events and some may perform it for combined disturbances. This section presents survey results of those references which includes only single disturbance such as sag, swell, inter

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ruption, transient, harmonic, notch. A different approach based on image processing (grayscale image and binary image) is used in [1] to detect the PQ disturbances. First, gray scale image of the disturbed voltage waveform is represented and this detects the disturbance area by comparing it with grayscale pattern of pure voltage waveform. In the next step image enhancement techniques are applied on the feature sets of the disturbances to make them more lively. For the classification purpose binary image analysis has been performed.

Optimal feature set play a vital role in analysis of PQ events. The performance of constructed features for a particular classifier has been noticed [23]. This started with large number of features and finally by using feature selection technique, useful feature subset has been extracted. The feature selection technique also depends on the classifier used. Hence in this paper features are optimized according to the classifier used which further helps in efficiently classifying the power quality events. For example in [30] S-Transform and TT-Transform are used for the purpose of feature extraction of the signal. And Probabilistic Neural Network based feature selection (PFS) is used for eliminating the non-essential features and is the combination of the Fully Informed Particle Swarm (FIPS) and an Adaptive Probabilistic Neural Network (APNN) techniques. The classifiers used in this paper are multilayer perceptron, k-nearest neighbor and APNN. The results indicate that this optimal feature selection technique improves the performance of the classifiers even in the noisy environment. Hence the use of feature selection technique gives the optimal feature set. In some cases only short duration disturbances such as sag, swell, transient have been considered. Reference based on this is [3] in which short duration disturbances are detected using modified potential function approach. Using this approach a Fast Real Time track and detection (FRTD) algorithm has been developed which gives the diffusion matrix. This parameter detects the presence of an PQ event in the signal and its threshold value classifies the power system disturbance. Another short duration disturbance detection technique is used in [13]. Here Discrete Wavelet Transform (DWT) is used for detecting the starting and ending point with the magnitude of the voltage sag and also for detecting the fast changes in the voltage signal that allows time localization of different frequency components of a signal with different frequency wavelets. Another different method for the classification of the Short Duration Disturbances (SDDs) is without using any classifier but by using the S-Transformed module time-frequency matrix (MTFM) [18] similarity scheme. This scheme is based on first establishing the standard MTFM for various SDDs and then calculating the similarity grade between the MTFMs of standard and tested SDDs. And then tested SDDs are classified according to this similarity scheme.

Authors focus on the use of statistical estimator such as to detect anomalies which mainly preserve the power line frequency. Variance, skewness, kurtosis are the estimators which were used for detection. Authors show the variation in estimators according to symmetric and asymmetric nature of disturbances. In such a way higher order statistical estimators [17] has been used for classification of PQ events.

III. Combined Type Of PQ Events

In this section the reviews of techniques are presented in which combination of two disturbances are considered. There are two cases mentioned, one in which combination is with only harmonics and other in which any combination of two disturbances are considered. A rule –based method [2] for the classification of the Power Quality (PQ) disturbances single as well as multiple is considered. Here multi-resolution S-Transform is used for the purpose of characterization as well as feature extraction of the signal. And these features characterize the signal successfully even in the presence of complex disturbances with different level of noise.

Another analysis performed by hybrid demodulation concept [4] and [36] described in four major steps. In the first step multiple PQ events have been differentiated from single events using Correlation and threshold values. In the next two steps events are analyzed depending upon whether they are single or combined. Afterwards in the last step separate knowledge bases have been designed for such events using hybrid demodulation and MUSIC algorithm concept. These knowledge bases are then utilized by the fuzzy classifier.

For detection as well as for classification of disturbances, intelligent method i.e. fuzzy systems are used along with Particle Swarm Optimization algorithm [25]. First fuzzy system expertise for detection purpose and second one for classification work. Feature extraction is performed using Fourier and wavelet transform of analyzed waveform. Extracted features are given to fuzzy systems as their inputs. To further improve the accuracy, PSO technique was used for optimization of parameters that are of membership function of fuzzy systems.

Wavelet based analysis also performed in [20] for both type of events, single as well as multiple DWT is used to denoise the distorted waveform and to extract feature vectors. To optimize the combination of feature vectors, principal component analysis approach is preferred. After this, feature vectors are applied to the wavelet network classifier for it's training. This works well even in the presence of noise. Coming paragraphs give some glance only on classification of harmonics combined with other disturbances.

The S-transform based fuzzy expert system (FES) in [26] has been proposed by the authors for PQ time series data mining. Data mining approach has been associated with fuzzy system to provide a certainty factor for each classification rule.

IV. Comparative Analysis

Table 1 shows the summary of some references which gives an idea about the techniques used for different purpose in the analysis of PQ. The advantages of the methodologies and approaches are also mentioned. Some have high classification accuracy, some are not sensitive to noise and many of them require less learning time. Hence in this way

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TABLE I. COMPREHENSIVE ANALYSIS OF SOME REPORTED ARTICLES

S. No	Reference no.	Type of disturbance	Feature extraction technique	Feature selection technique	Feature classifier	Advantage of technique used
1.	C.H.Huang et al. [5]	Multiple (only harmonics combined)	Chaos-Synchronization based detector	PSO	PNN	Fast Learning & processing
2.	K.Manimala et al. [29]	Multiple(only harmonics combined)	Wavelet Packet Transform	GA and Simulated annealing	SVM	Better than Conventional Classifier
3.	A.Abdelalam et al. [33]	Multiple (only harmonics combined)	Kalman Filter		FES	Computation time is less than Conventional
4.	M.A.S.Masoum et al.[20]	Multiple	DWT	Principal component analysis	Wavelet Network classifier	Accurate, robust and fast technique.
5.	M.Uyar et al.[24]	Multiple(only harmonics combined)	S-Transform	—	NN based on MLP	Classification accuracy is 99.67%
6.	J.S.Decanini et al.[15]	Multiple(only harmonics combined)	DWT, MRA	—	Fuzzy-ARTMAP NN	Classification accuracy is 99.66% .
7.	Z.He et al. [28]	Various transients	Wavelet Transform	Wavelet energy entropy & Wavelet entropy weight	BPNN	requires shorter training
8.	B.Biswal et al. [27]	Multiple (only harmonics combined)	S-Transform with modified Gaussian window (MGW)	Adaptive PSO	Fuzzy C-mean clustering	MGW results in good accuracy
9.	C.Lee et al.[30]	Single	S and TT transform	PNN	MLP, APNN	Feature Selection is efficient
10.	H.He et al. [21]	Single	Energy difference multiresolution analysis (EDMRA)		EDMRA	Not sensitive to noise

depending upon the characteristics of methods various disturbances can be classified properly.

V. CONCLUSIONS AND FUTURE SCOPE

This paper shows the review of the techniques that are consistently using for the analysis of PQ. Different techniques used for extracting the feature, then for the feature selection and finally for the classification, are described from their behavior. Benefits of various new methods are examined in terms of classification accuracy, noise tolerance, computation time, etc. Recommendation of any technique depends upon the characteristics of the techniques and requirement in the analysis of PQ events. The large literature shows that the field of PQ analysis is growing. Hence the paper concludes that there are some techniques which require large computational resources and sometimes large amount of data are required to be continuously monitored. Hence for the future purpose we may move towards the new techniques which deal with such a problem. And another thing which has been noticed is that new methodologies should be proposed which becomes able to detect and classify single as well as combined disturbances (which contains any combination of disturbance).

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